

NASA TM X-55839

**D REGION
ELECTRON DENSITY MEASUREMENTS
DURING THE SOLAR ECLIPSE
OF MAY 20, 1966**

J. A. KANE

FACILITY FORM 602	N67-31852	_____
	(ACCESSION NUMBER)	(THRU)
	18	1
	(PAGES)	(CODE)
	TMX-55839	13
	(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

JUNE 1, 1967



GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

D REGION ELECTRON DENSITY MEASUREMENTS DURING THE SOLAR ECLIPSE
OF MAY 20, 1966

J. A. Kane

Laboratory for Space Sciences
NASA Goddard Space Flight Center

ABSTRACT

Rocket (Underwood and Muney, 1967) and satellite observations of $1-8\overset{\circ}{\text{A}}$ X-ray emissions indicate that the solar eclipse of May 20, 1966, occurred during a period in which the sun was moderately active. The Goddard Space Flight Center conducted a series of small sounding rocket experiments to measure the ionospheric D region electron density profile during successive stages of the eclipse. From these measurements together with the available X-ray data it is concluded that $1-8\overset{\circ}{\text{A}}$ X-rays were not the dominant source of D region ionization below 78 km.

INTRODUCTION

It is generally believed that during quiet sun conditions the D region of the ionosphere (i.e. the altitude interval between 70 and 85 km) is produced by the Lyman alpha ionization of nitric oxide. However, during periods of increased solar activity the flux of kilovolt X-rays penetrating the D region increases by orders of magnitude while the Lyman alpha flux remains constant. At some level of activity it can be expected that the production of D region ionization by X-rays will exceed the Lyman alpha-nitric oxide contribution. At any given time however it is difficult to evaluate the relative weights of these two ionization sources because the nitric oxide concentration is a gross uncertainty. An alternative to this impasse might be provided by the conditions at a solar eclipse.

The May 20, 1966 solar eclipse occurred during a period in which the sun was moderately active. X-ray photographs of the sun (Underwood and Muney, 1967) on the day of the eclipse show three active regions for emissions in the $3-11\overset{\circ}{\text{Å}}$ wavelength interval. By the covering and uncovering of these spots the solar eclipse provides an ideal situation for studying the effects of these X-rays on the D region ionization content.

The path of the May 20, 1966 solar eclipse as it passed over Greece is shown in Figure 1. In collaboration with the Ionospheric Institute of the University of Athens, the Goddard Space Flight Center conducted a series of ARCAS rocket experiments to measure the D region electron density profile during successive stages of the eclipse. The experimental site was located on the beach at Koroni in the southern Peloponese, while the rocket launchings took place from a ship located approximately 3 km off shore.

The rocket firing schedule together with the pertinent

parameters of the eclipse are given in Table 1. The eclipse data refers to a location close to the peak of the rocket trajectory.

TABLE 1

Date	Event	Local Time	Zenith Angle	Illumination		Solar Activity***
				Lyman Alpha*	(X-ray)**	
May 20	First Contact	10:00				114
	Zorba II	10:00	37 ⁰ .0	1.00	1.00	
	Zorba III	10:45	28 ⁰ .0	0.53	0.66	
	Eclipse Maximum	11:25				
	Zorba IV	11:30	21.5 ⁰	0.09	0.00	
	Zorba V	12:15	17.2 ⁰	0.66	0.83	
	Zorba VI	13:00	18.0 ⁰	1.00	1.00	
	Last Contact	13:00				
May 21	Zorba VII	11:30	21.5 ⁰			121

* Proportional to uneclipsed solar disc area.

** 1-8Å X-ray band

*** 2800 Mc/s flux (High Altitude Observatory, Boulder, Colorado).

EXPERIMENTAL METHOD

The electron density profiles were determined from radio propagation measurements. The well known Faraday rotation and differential absorption effects were measured on cw radio transmissions at 2.73 and 4.03 Mc/s. For each frequency a linearly polarized signal was radiated from a ground based antenna and received on a separate linearly polarized antenna in the rocket. The mechanical spin of the rocket of about 25 cycles per seconds

was used to rotate receiving antenna through the polarization pattern of the arriving wave. The telemetered signal strength exhibited a fading pattern which was the sum of the rocket spin frequency and the ionospheric Faraday rotation. A comparison of this fading pattern with the mechanical spin period yielded the altitude variation of the plane of polarization. The mechanical spin period was obtained from the fading pattern of the 240 Mc/s telemetry carrier frequency as observed on the ground with a linearly polarized receiving antenna.

Differential absorption data is also obtainable from the fading pattern of the received signal strength. This follows from the fact that the maxima in the signal strength represents the sum, while the nulls represent the difference in the ordinary and extraordinary components of the linearly polarized wave.

Under the condition of quasi-longitudinal propagation, the plane of linear polarization, defined by the angle φ , rotates with rocket altitude z according to an expression of the form:

$$\frac{d\varphi}{dz} = N_e(z) F(\omega, \omega_H, \nu(z)) \quad (1)$$

where $N_e(z)$ is the electron density and F is a calculated function of the exploring frequency ω , the electron gyro frequency ω_H and the collision frequency ν . The explicit form of F involves the Dingle integrals of the generalized Appleton-Hartree formula (see, for example, Sen and Wyller, 1960).

Differential absorption can be related to the ionospheric parameters by a similar expression. Denoting the received signal strengths of the two polarization modes as E_o and E_x the altitude variation of the logarithmic ratio $\ln(E_o/E_x)$ can be expressed as

$$\frac{d}{dz} \ln(E_o/E_x) = N_e(z) G(\omega, \omega_H, \nu(z)) \quad (2)$$

where again $N_e(z)$ is the electron density and $G(z)$ is a calculated altitude - dependent function involving the Dingle integrals. Before either $F(z)$ or $G(z)$ can be calculated it is necessary to assume a collision frequency model. In Table II is listed the collision frequency model used in the present work. This model was based on the mean monthly pressure data of Kantor and Cole (1965) and the relationship of Phelps (1960)

$$\nu = 6.28 \times 10^7 p \text{ (sec}^{-1}\text{)} \quad (3)$$

where p is the atmospheric pressure in millibars.

ELECTRON DENSITY RESULTS

Electron density profiles were obtained for all six rocket flights. The experimental method yielded four sets of data:

1. Faraday rotation on 2.73 Mc/s (240 Mc/s reference).
2. Faraday rotation on 4.03 Mc/s (240 Mc/s reference).
3. Difference Faraday (2.73 Mc/s compared to 4.03 Mc/s).
4. Differential absorption on 2.73 Mc/s.

The relative quality of any one of these sets of data varied from flight to flight. This was due to both external and internal causes. Externally some radio interference on 2.73 Mc/s was encountered. Internally, the radiation pattern of the 240 Mc/s transmitting antenna apparently underwent some detuning during flight. This resulted in a Faraday reference signal too crude for the measurement of the small electron density in the lower altitude region. In this region the electron density profile was obtained from the difference Faraday (i.e. the 2.73 fading pattern compared with the 4.03 pattern) and differential absorption on 2.73 Mc/s.

Figure 2 shows the spread on the electron density values derived from three sets of data obtained on flight labeled

Zorba VI. A similar spread for each Zorba flight determined the uncertainty assigned to the final electron density profiles given in Table II. The individual profiles of Table II are summarized in figure 3. This shows that most of the effect of the eclipse upon the D region electron density profile apparently occurs near totality.

X-RAY INFORMATION

In figure 4 are shown maps of the eclipsed sun as viewed from near the peak of each Zorba rocket trajectory. These maps (which were kindly provided by A. C. Aikin) show the location of the regions of 3-11 Å X-ray emissions as determined by Underwood and Muney (loc. cit.). Also obtained by Underwood and Muney was the 20 May X-ray spectrum in the 1-8 Å band from which a D region ion production function can be calculated. This will be given in the next section.

The eclipse was observed in the 1-8 Å X-ray band by a photometer aboard the SOLRAD 8 satellite. From this data Landini et al (1966) obtained the relative weights of the West, Central and East X-ray spots as 3, 2 and 1 respectively. These weights together with the maps of figure 4 determined for each Zorba flight the relative X-ray illumination given in Table I.

DISCUSSION

As indicated in Table I, from one Zorba flight to the next, the change in X-ray flux is almost identical to the change in the Lyman alpha illumination. This situation prevents us from seeing a pure X-ray effect in a comparison of the Zorba electron density profiles. From the profiles we can however establish a lower limit on the magnitude of the ion production function q , which appears in the electron production and loss equation as

$$q = \frac{dN}{dt} + \alpha N^2 \quad (4)$$

Here N is the electron density and α is an effective recombination coefficient. For a positive value of dN/dt (i.e. during the recovery phase of the eclipse)

$$q \geq \frac{dN}{dt} \geq \frac{\Delta N}{\Delta t} \quad (5)$$

In figure 5 is a plot of $\frac{\Delta N}{\Delta t}$ obtained from a comparison of the electron density profiles of Zorba IV and Zorba V. These measurements were separated in time by 45 minutes. Included in figure 5 is the ion production function obtained by Bowling et al (1967), from the 20 May X-ray spectra data of Underwood and Munev. From figure 5 it can be concluded that on 20 May 1966 a source other than $1-8\overset{\circ}{A}$ X-rays dominated the ionization of the D region below 78 km.* See footnote page 8

On 20 May the integrated energy flux in the $1-8\overset{\circ}{A}$ band was 5×10^{-4} ergs/cm²sec. On the following day at the time of the Zorba VII control shot the integrated energy flux in the $1-8\overset{\circ}{A}$ band had increased to 1.2×10^{-3} ergs/cm²sec (R. W. Kreplin, private communication). A comparison of electron density profiles for Zorba VII and Zorba VI listed in Table II shows that this increased X-ray flux apparently did not lead to any pronounced increase in the D region electron density values.

CONCLUSION

The integrated energy flux in the $1-8\overset{\circ}{A}$ X-ray band must exceed a value of 10^{-3} ergs/cm²/sec to disturb the electron density in the D region below 80 km. This assumes of course that the spectral distribution is a monotonic function of energy. This point together with the value of the threshold energy flux

for D region effects will be clarified as more simultaneous electron density profiles and X-ray spectral measurements become available during the upcoming years of increased solar activity.

ACKNOWLEDGEMENTS

This work was made possible through an international cooperative program between NASA and the Greek National Committee for Space Research. We are especially grateful to Professor Michael Anastassiadis and Dr. D. Ilias for valuable assistance with the field operations. Mr. E. Bissell was the NASA Project Manager.

FOOTNOTE

Implicit in this argument is the assumption that negative ions do not provide a significant sink and source of electrons during the eclipse. However if this assumption is invalid we can still conclude that X-rays were not the dominant ionization source below 78 km. We argue as follows: for the conditions existing at the end of the eclipse (i.e. $\frac{dN}{dt} = 0$) we can calculate the effective recombination coefficient $\alpha_{\text{eff}} = q_x / N_{\text{VI}}^2$ from the Zorba VI electron density profile and the ion production function q_x due to X-rays alone. The results are given in Table III.

Table III

Z(km)	$q_x (\text{cm}^{-3} \text{sec}^{-1})$	$N_{\text{VI}} (\text{cm}^{-3})$	$\alpha = q_x / N^2$
80	4.0×10^{-1}	870 ± 80	$(5.3 \pm 1.0) \times 10^{-7}$
75	8.5×10^{-2}	620 ± 60	$(2.2 \pm 0.4) \times 10^{-7}$
70	2.0×10^{-2}	280 ± 50	$(2.5 \pm 0.9) \times 10^{-7}$

Since $\alpha_{\text{eff}} = (1 + \lambda) (\alpha_d + \lambda \alpha_i)$ where $\lambda \equiv N_- / N_e$ (i.e. the ratio of the densities of negative ions to electrons) is a decreasing function of altitude, it is required that α_{eff} also be a decreasing function of altitude. Since the values of α in Table III do not satisfy this altitude dependence, we conclude that X-rays alone do not produce the D region below approximately 80 km.

TABLE II

Z	ν	N _{II}	N _{III}	N _{IV}	N _V	N _{VI}	N _{VII}
67	5.27x10 ⁶				40 ⁺ -50	130 ⁺ -50	120 ⁺ -170
69	3.89	145 ⁺ -60			60 ⁺ -50	220 ⁺ -50	230 ⁺ -50
71	2.83	240 ⁺ -60	160 ⁺ -90		160 ⁺ -50	330 ⁺ -50	380 ⁺ -50
73	2.05	345 ⁺ -50	350 ⁺ -165	15 ⁺ -60	350 ⁺ -70	550 ⁺ -85	560 ⁺ -60
75	1.47	430 ⁺ -100	480 ⁺ -50	28 ⁺ -50	450 ⁺ -50	620 ⁺ -60	690 ⁺ -90
77	1.04	500 ⁺ -260	520 ⁺ -50	48 ⁺ -50	550 ⁺ -50	690 ⁺ -50	780 ⁺ -100
79	7.22x10 ⁵		550 ⁺ -50	77 ⁺ -50	660 ⁺ -50	740 ⁺ -80	850 ⁺ -50
81	5.15		580 ⁺ -50	115 ⁺ -50	780 ⁺ -50	1000 ⁺ -80	960 ⁺ -180
83	3.61		900 ⁺ -100	155 ⁺ -50	1100 ⁺ -80	2000 ⁺ -280	1150 ⁺ -180
85	2.51		1800 ⁺ -350	225 ⁺ -50	2000 ⁺ -370	2900 ⁺ -150	2000*
86							3400*
87	1.75		3500 ⁺ -1700	660 ⁺ -80	2550 ⁺ -880	4500 ⁺ -325	7000*
88.5							
89	1.22		6000 ⁺ -670	1500 ⁺ -280	4600*	10,000*	
90					6600*		
91	8.49x10 ⁴		11000 ⁺ -3750	3300 ⁺ -380	10,000*		
92				5700 ⁺ -300			
93	6.03		22000 ⁺ -13750				

* Based on 4.0 Mc/s Faraday data only.

REFERENCES

- Bowling, T. S., K. Norman and A. P. Wilmore, D-region measurements during a solar eclipse, Unpublished manuscript, 1967.
- Kantor, A. J. and A. E. Cole, Monthly atmospheric structure surface to 80 km, J. Appl. Meteorol., 4, 228-247, 1965.
- Kreplin, R. W., private communication, 1967.
- Landini, M., D. Russo and G. L. Tagliaferri, Solar eclipse of May 20, 1966 observed by the Solrad 8 Satellite in X-ray and ultra-violet bands, Nature, 211, 394, 1966.
- Phelps, A. V., Propagation constants for electromagnetic waves in weakly ionized air, J. Appl. Phys., 31, 1723-1729, 1960.
- Sen, H. K. and A. A. Wyller, On the generalization of the Appleton-Hartree magnetoionic formulas, J. Geophys. Res. 65, 3931-3950, 1960.
- Underwood, J. H. and W. S. Muney, A glancing incidence solar telescope for the soft X-ray region, Solar Phys. 1, 129-144, 1967.

FIGURE CAPTIONS

- FIGURE 1 Path of the May 20, 1966 eclipse in Greece. Rocket experiments were conducted at Koroni.
- FIGURE 2 Spread on Zorba VI electron density values deduced by three separate methods.
- FIGURE 3 Electron density profiles obtained during the course of the May 20, 1966 eclipse.
- FIGURE 4 Obscuration of the sun as viewed near the peak of each Zorba trajectory. Included in each map are isopleths of X-ray emission in the 3-11Å band.
- FIGURE 5 Experimental determination of the minimum ion production function. The solid curve was calculated by Bowling et al from the 20 May X-ray spectra measured by Underwood and Muney.

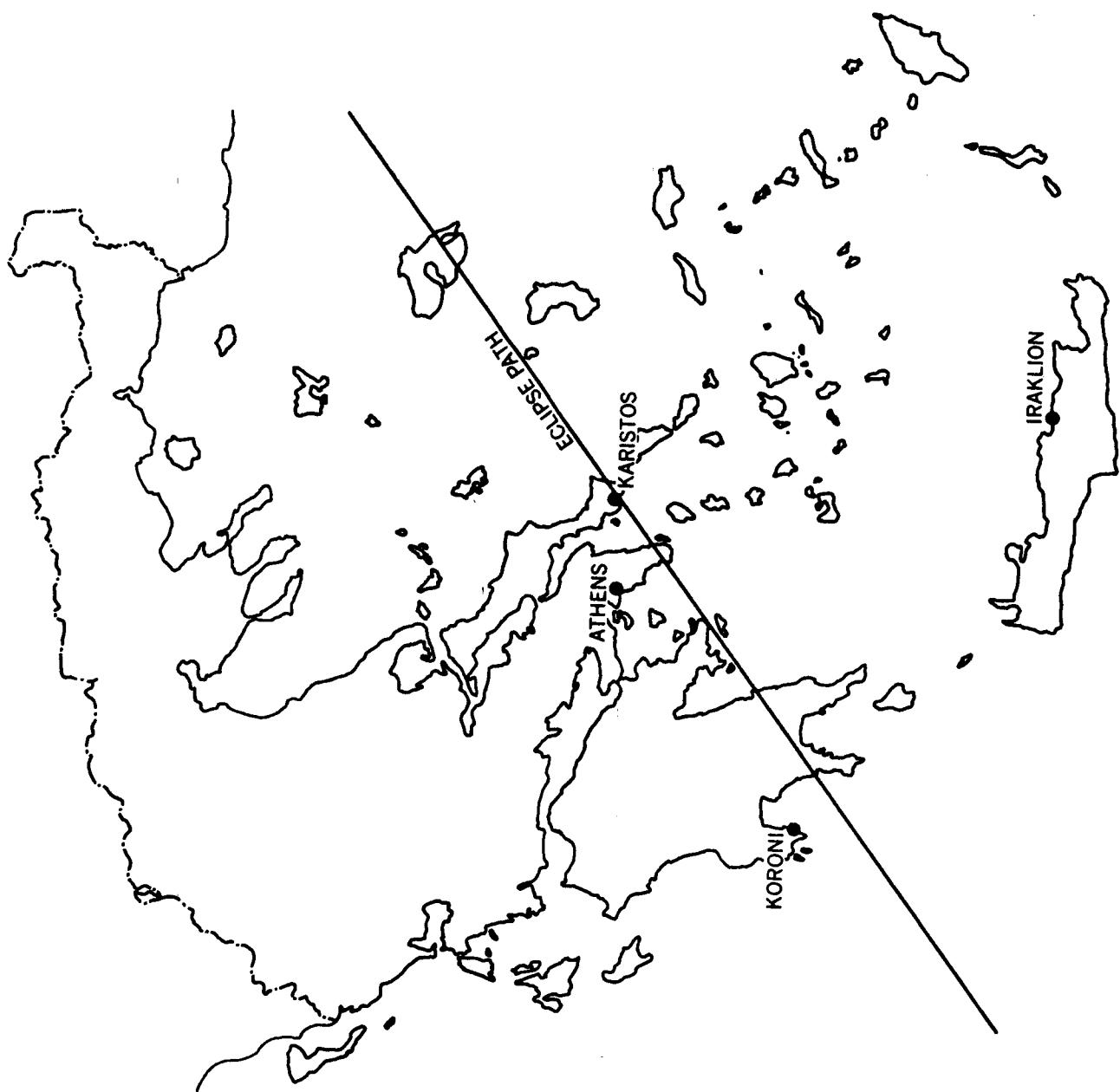


Figure 1.

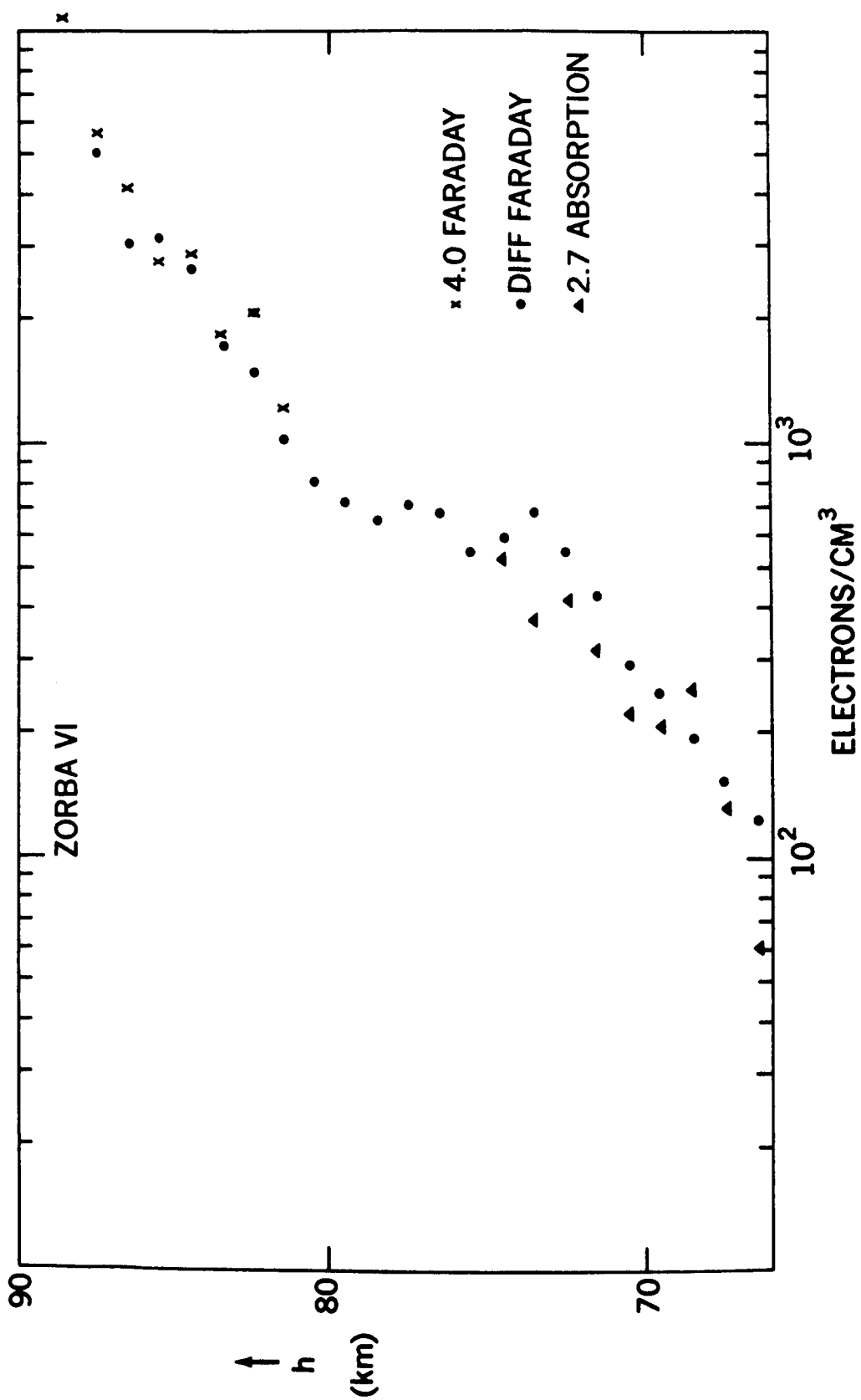


Figure 2.

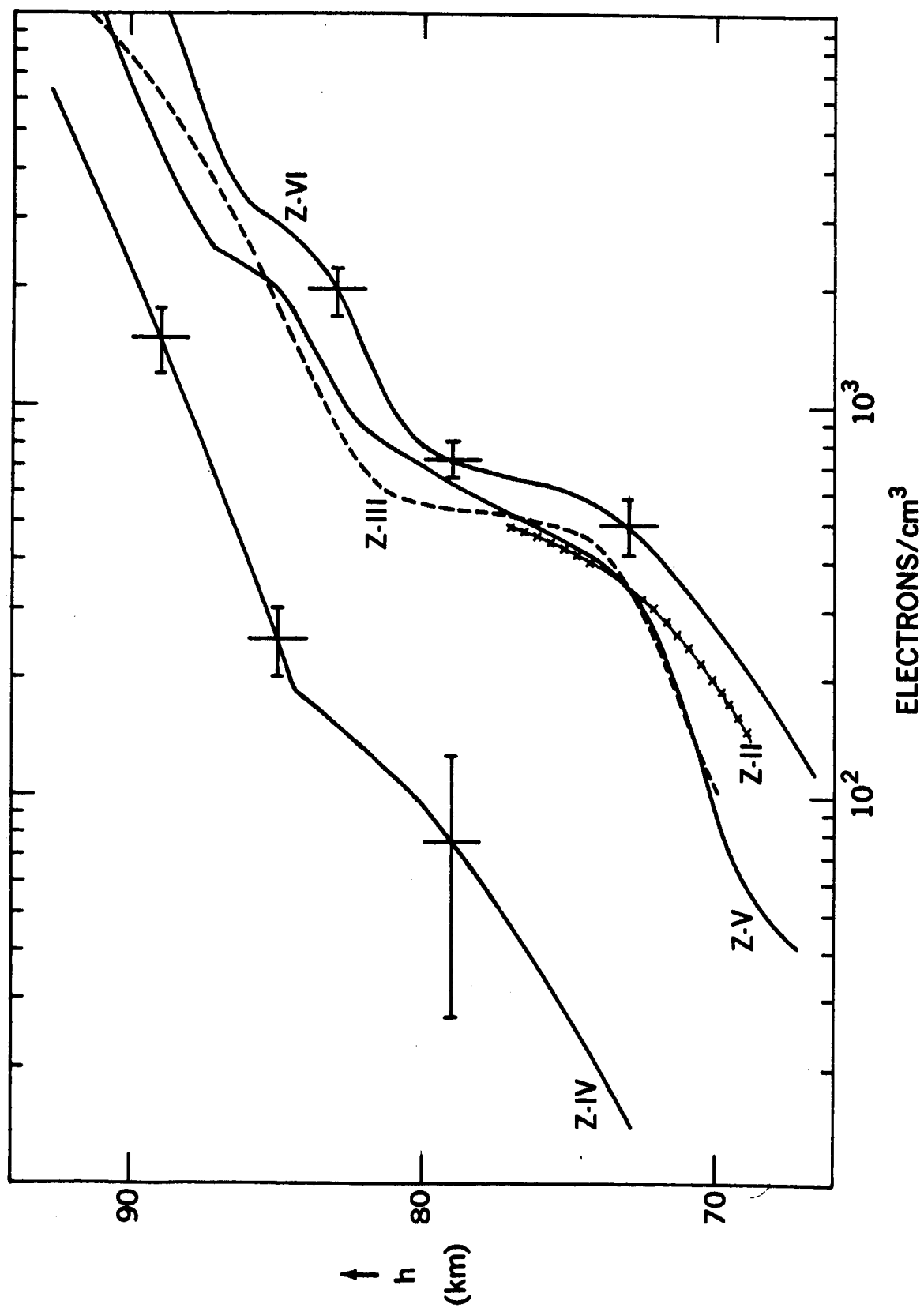


Figure 3.

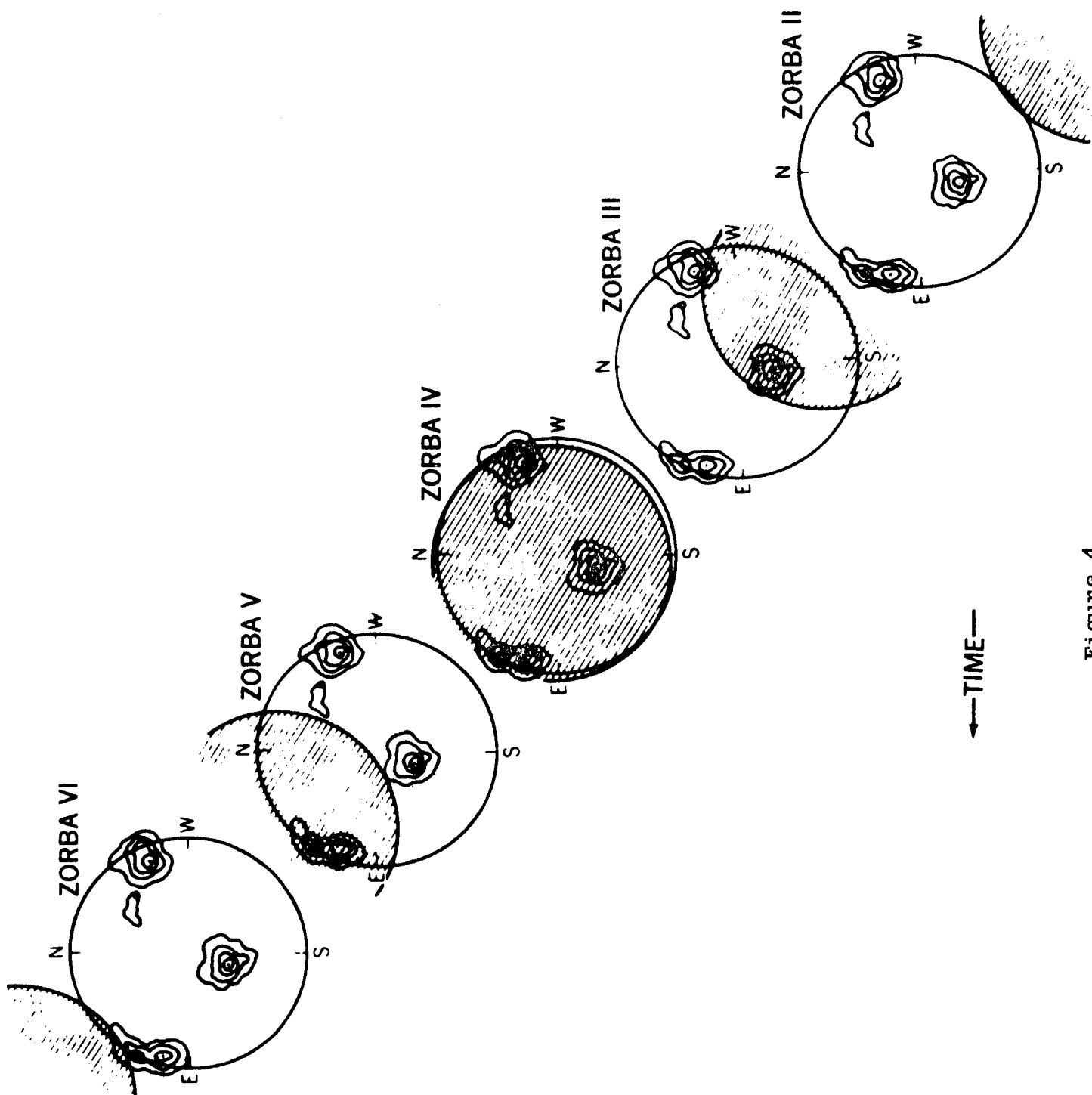


Figure 4.

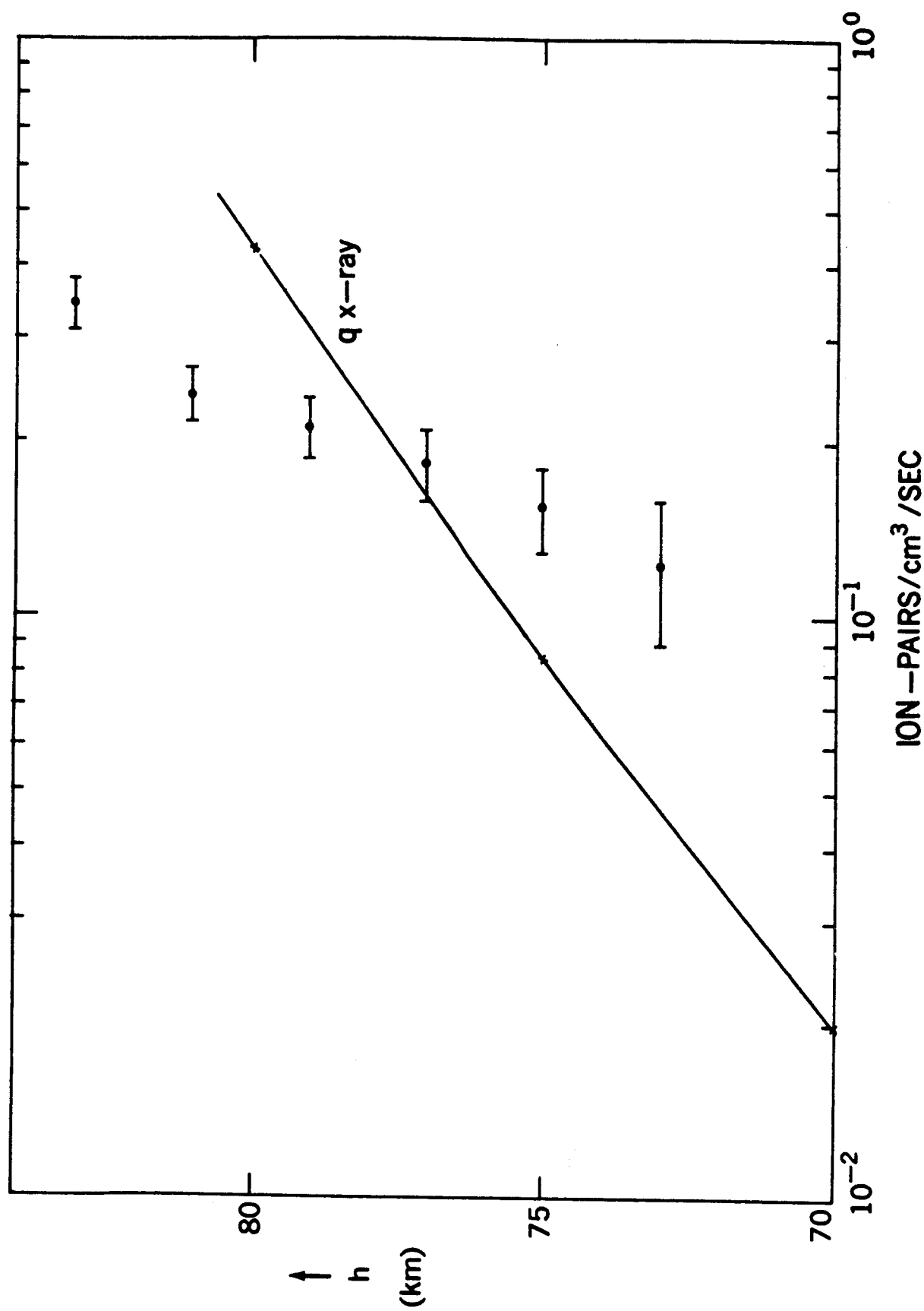


Figure 5.